Computational Study: Dynamic Reversal Potentials in a Conductance-based Synaptic Model

COMPUTATIONAL STUDY: DYNAMIC REVERSAL POTENTIALS IN A CONDUCTANCE-BASED SYNAPTIC MODEL

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Introduction

Synapses are points of information transfer between neuronal cells which operate on a micrometre scale. Due to their small size, computational modelling is used to study synaptic behaviour [1]. Traditional synaptic models assume an infinite extracellular space surround synapses and therefore, these models assume constant reversal potentials [2]. However, recent evidence suggests that many synapses are tightly wrapped by astroglial cells [3]. Therefore, we use the assumption that the extracellular space around chemical synapses is finite due to an enwrapped astrocyte to investigate how this will affect reversal potentials in the neuron.

Aims and Objectives

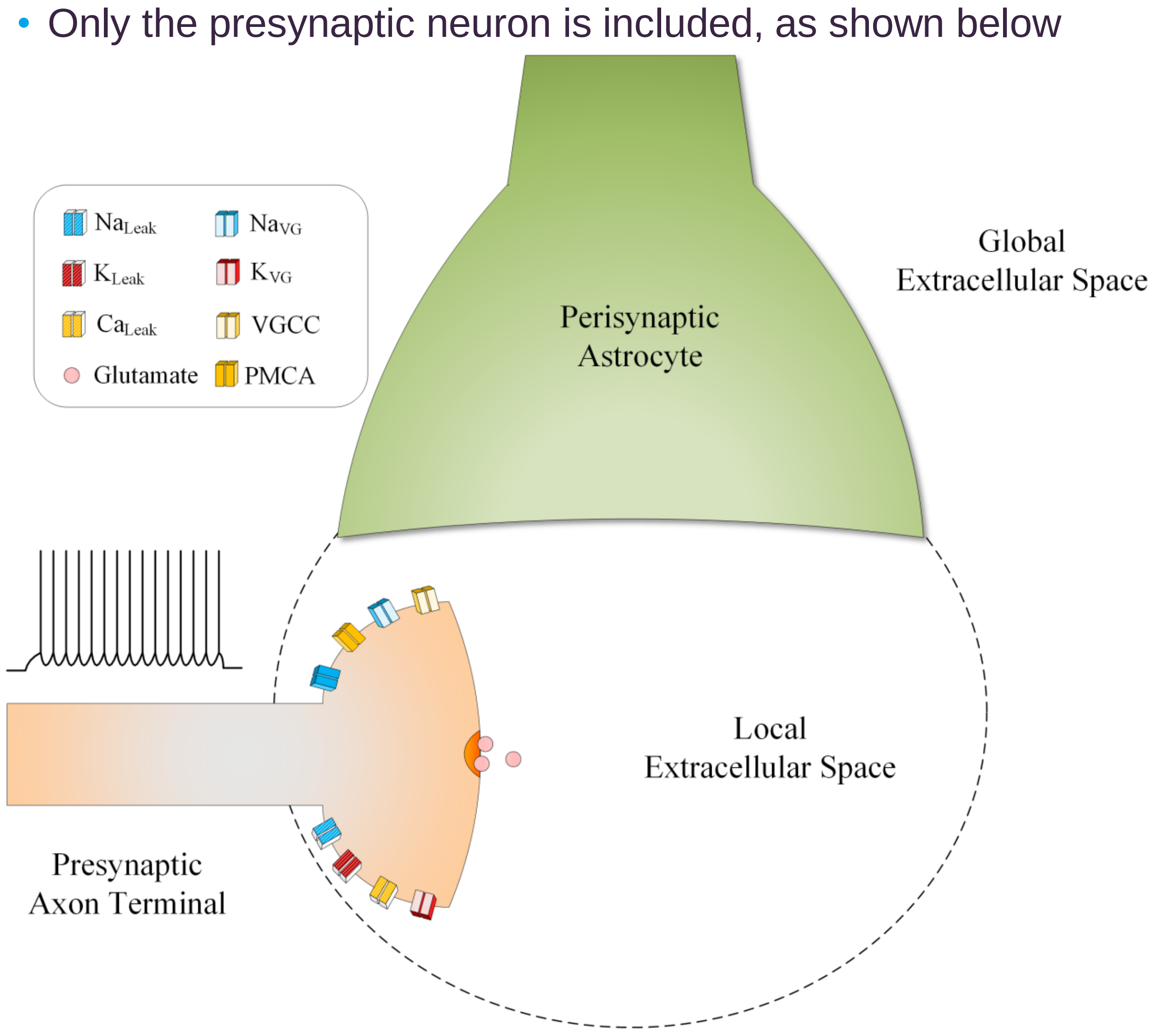
- Our main aim is to investigate whether a perisynaptic astrocyte can impact the behaviour of reversal potentials or the membrane potential in a conductance-based synaptic model
- To achieve this aim, we use the traditional Hodgkin-Huxley formulism to simulate a hippocampal synapse that is surrounded by an astrocyte [2]

Hypothesis

- We hypothesize that a finite extracellular space will change reversal potentials at the synaptic bouton

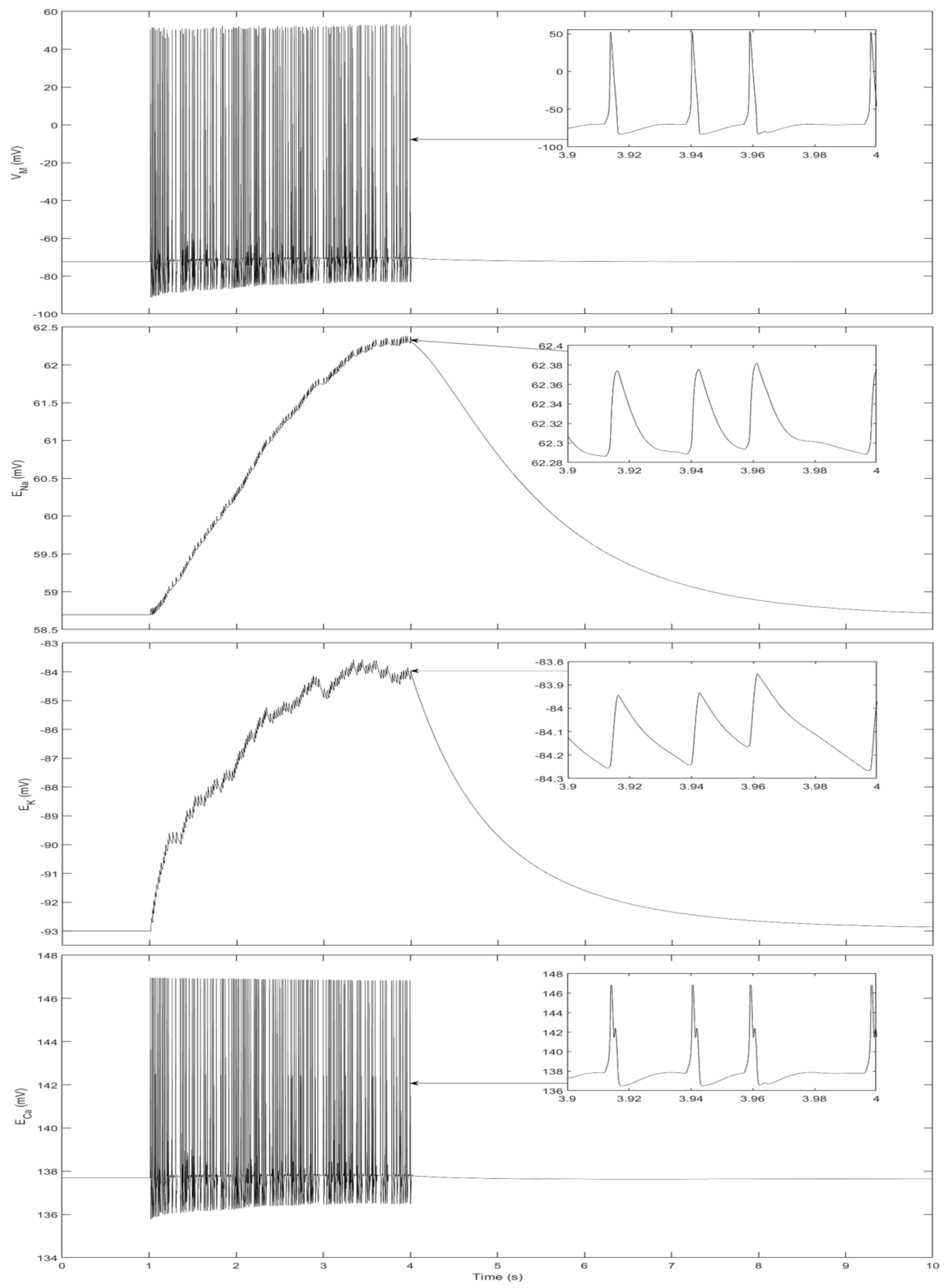
Methods

- A first-order mathematical framework is used to simulate a conductance-based synaptic model
- A perisynaptic astrocyte is used to create a finite extracellular space (see schematic below)
- Dynamic reversal potentials are used instead of constant reversal potentials
- Only the presynaptic neuron is included, as shown below



Results

- Simulations ran for 10 seconds using a 10Hz Poisson spike train for 3 seconds of stimulation
- All potentials are in millivolts, inset shows 100ms of detail
- Results show, from top to bottom, membrane potential, Na^+, K^+ and Ca^{2+} reversal potentials



Conclusions

We found that using a finite extracellular space can significantly affect reversal potentials. However, the membrane potential behaviour remains largely unaffected. Therefore, we conclude that using the assumption of constant reversal potentials is a good approximation even at the small scales of a single synapse.

References

[1] E. R. Kandel, J. H. Schwartz, T. M. Jessell, S. A. Siegelbaum, and A. J. Hudspeth, Principles of Neural Science, Fifth. McGraw-Hill, 2012

[2] Hodgkin, A. L., & Huxley, A. F. (1952). A quantitative description of membrane current and its application to conduction and excitation in nerve. The Journal of Physiology, 117(4), 500–544. https://doi.org/10.1007/BF02459568

[3] Verkhratsky, A., & Nedergaard, M. (2014). Astroglial cradle in the life of the synapse. Philosophical Transactions of the Royal Society B: Biological Sciences, 369(1654), 20130595–20130595. https://doi.org/10.1098/rstb.2013.0595

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